Excessive Shaft Friction Variation Corrected by Lubricant Change

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During testing of the Master Equatorial for the 64-m-diameter antenna under construction in Australia, a drag torque variation ratio as large as 5 to 1 was observed on a shaft supported by two angular contact ball bearings. A change in the grease lubricant reduced the ratio to 1.1 to 1.0.

I. Introduction

During the testing of the assembled Master Equatorial for the 64-m-diameter antenna under construction in Australia, it was discovered that the polar axis drag torque was erratic. Figure 1 shows the position of the angular contact bearings and the forces acting on them. The axial load on the bearing can be varied by changing the thickness of a shim under the lower bearing retainer. The breakaway torque, that is, the torque required to produce a visible movement from a dead stop condition, varied from 9 to 51 m N. When the movement was just barely visible, the torque variation was considerably less but still much more than is desired.

The Master Equatorial was moved to an appropriate disassembly area and placed so that its polar axis was vertical, with the large bearing above the small bearing. Drag torque tests produced approximately the same results as those obtained with the polar axle at its normal operating attitude, i.e., inclined 35 deg from the horizontal. Next the bearing preload shim was removed, thus reducing the thrust load on the upper bearing to 11000 N, the weight of the rotating fork assembly. The load on the lower bearing was zero. Many rotation tests were made at this configuration. The breakaway torques ranged from 7.9 to 39.5 m N, with values between 23 and 27 occurring frequently. During very slow movements, the torques ranged from 6.8 to 18.0 m N.

Immediately following a rapid turn of the axle, the slow-speed torque was likely to be near 7 m N, but as the barely visible motion continued, the drag torque increased. When the motion was stopped, following several seconds of slow rotation, the breakaway torque usually was between 23 and 40 m N, although occasionally an 8- to 11-m N breakaway was found. The polar axle was disassembled, and extraneous drag spots were searched for. None was found. The bearings were removed and taken, together with nominally identical spare bearings, to a bearing inspection laboratory[1] for further testing.

[1]Bearing Inspection Inc., Santa Fe Springs, Calif.

II. Individual Bearing Tests

The small polar bearing was tested first. It is a standard size, angular contact ball bearing with a 150-mm bore, 225-mm outside diameter, and a width of 35 mm, and contains 22 balls of 22.20-mm diameter in a phenolic resin retainer. It was placed on a table with its axis vertical and loaded to 178 N axially. The breakaway drag torque varied from 0.045 to 0.113 m N. It definitely did not exhibit the characteristics of the installed Master Equatorial polar axle.

Next the large bearing (JPL part number 9435532) was tested. It is a special size, angular contact ball bearing with a 300-mm bore, 360-mm outside diameter, and a width of 33.20 mm, and contains 48 balls of 17.5-mm diameter in a phenolic resin retainer. It was placed with its axis vertical and loaded axially to 334 N. After slow turning by hand in the counterclockwise direction for several turns, an erratic drag torque developed which appeared to be the same as that experienced on the installed axle. The breakaway torque ranged from 0.28 to 1.86 m N. When a small motion was maintained, the torque variation was much smaller but still considerably more than desired.

In order to determine whether the problem was peculiar to this particular bearing, another nominally identical one was tested. Its breakaway torques ranged from 0.17 to 1.62 m N, essentially the same as those of the first one.

The large bearing was then spun as rapidly as possible by hand (estimated at two revolutions per second) for ten to twenty turns. Immediately afterwards, both the slowly moving and breakaway torques were reduced to approximately 0.23 m N, but after a few seconds they were back to much higher values. These tests were repeated several times with the same results. Both directions of rotation were tried.

It was surmised that in some way the lubrication was at fault. The grease in both the large and small bearings (grease No. 1)[2] had been selected with particular emphasis given to its ability to prevent fretting corrosion during shipment to the overseas site.

Two large bearings were cleaned of grease and tested dry under the 334-N axial load. Many slow turns were made in both directions searching for the large torque variations, but none was found. Then spin-down tests were made. The bearing angular speed was measured and the time interval to reach zero speed recorded. The average decelerations were 0.304 rad/s^2 clockwise and 0.284 rad/s^2 counterclockwise for serial number 001 bearings. For serial number 003 bearings, the clockwise and counterclockwise average decelerations were 0.264 and 0.260 rad/s^2, respectively. The torques computed from these decelerations range from 0.059 to 0.050 m N, which was roughly the values obtained from a torque wrench while moving the bearing slowly.

Next a large polar bearing was lubricated with a very light oil (MIL-L-6085A), and many slow turns were made. The torque variation was very small.

A large polar bearing was filled with grease No. 2,[3] which is the lubricant used in the Master Equatorial bearings at DSS 14, and loaded to 334 N axially. Grease No. 2 is a very stiff channeling grease, and many turns were required to obtain the most favorable performance. After a few hundred turns, drag breakaway torques of 0.56 to 0.68 m N were measured. A slow motion typically required 0.90 to 1.0 m N. No large torque variations were found.

The other large bearing (serial number 001) was filled with No. 3 grease[4] and loaded to 334 N axially. This grease is also a channeling grease but channels much faster than No. 2. After only a few turns, the breakaway torques ranged from 0.11 to 0.17 m N, and the slow-moving torques were approximately the same. Many slow turns were made searching for the phenomenon of high torque variation, but it was never found.

III. Polar Axle Test

The large and small bearings, both refilled with grease No. 3, were re-installed in the Master Equatorial. With the polar axle vertical and no preload shim installed, the breakaway drag torques ranged from 2.6 to 2.8 m N, and the barely visible moving torques were the same.

The preload shim thickness was adjusted to increase the preload by an estimated 8900 N, that is, the large bearing thrust load was increased from 11,100 to 20,000 N and the small bearing thrust from 0 to 8900 N. The breakaway torques varied from 7.3 to 7.9 m N, and the moving

[2]Aeroshell 7.

[3]Andoc C.

[4]Anderol 757.

torques were the same. A hundred or more slow turns were made searching for large torque variations, but none was found.

IV. Conclusions

The comparative drag torque values for the large polar bearing are shown in Table 1. A dramatic reduction in torque variation ratio, namely from 5.60 to 1.07, was obtained by changing from grease No. 1 to grease No. 3.[5]

Three different types of angular contact ball bearings are used on the Master Equatorial. When lubricated with grease No. 1, two types performed acceptably, whereas the performance of the third was most unsatisfactory. It is interesting to note that the large polar bearing is of a special size, whereas the small polar bearing and the declination axis bearings are of standard size. The large polar bearing is slightly smaller in cross section but almost twice as large in pitch diameter as the small polar bearing. Hence, its bearing retainer is much more flexible than that of the small polar bearing. It was noticed that these flexible retainers were slightly elliptical.

It is believed the erratic action of the large polar bearing, when filled with grease No. 1, can be explained as follows: During a sufficiently fast rotation, the major diameter of the elliptical retainer sweeps a circular grease boundary which stays put. Between the grease boundary and the minor diameter of the ellipse, a space exists. But at very slow speeds, the grease sloughs off into this space, and has to be continually plowed out of the way as rotation continues, thus causing a variation in drag torque.

[5]Both No. 1 and No. 3 contain a diester oil. The thickener in No. 3 is lithium soap, that in No. 1 is "Microgel."

Table 1. Torque value ranges

Conditions	Grease No. 1		Grease No. 2		Grease No. 3	
Large polar bearing configuration	Breakaway torque, m N	Slow-moving torque, m N	Breakaway torque, m N	Slow-moving torque, m N	Breakaway torque, m N	Slow-moving torque, m N
Installed in Master Equatorial, normal position	51 9				7.90 7.35	7.90 7.35
Installed in Master Equatorial, polar axis vertical, reduced preload	39 8	18 7			2.8 2.6	2.8 2.6
Test bench, 334-N thrust	1.86 0.28		0.68 0.56	1.0 0.9	0.17 0.11	0.17 0.11

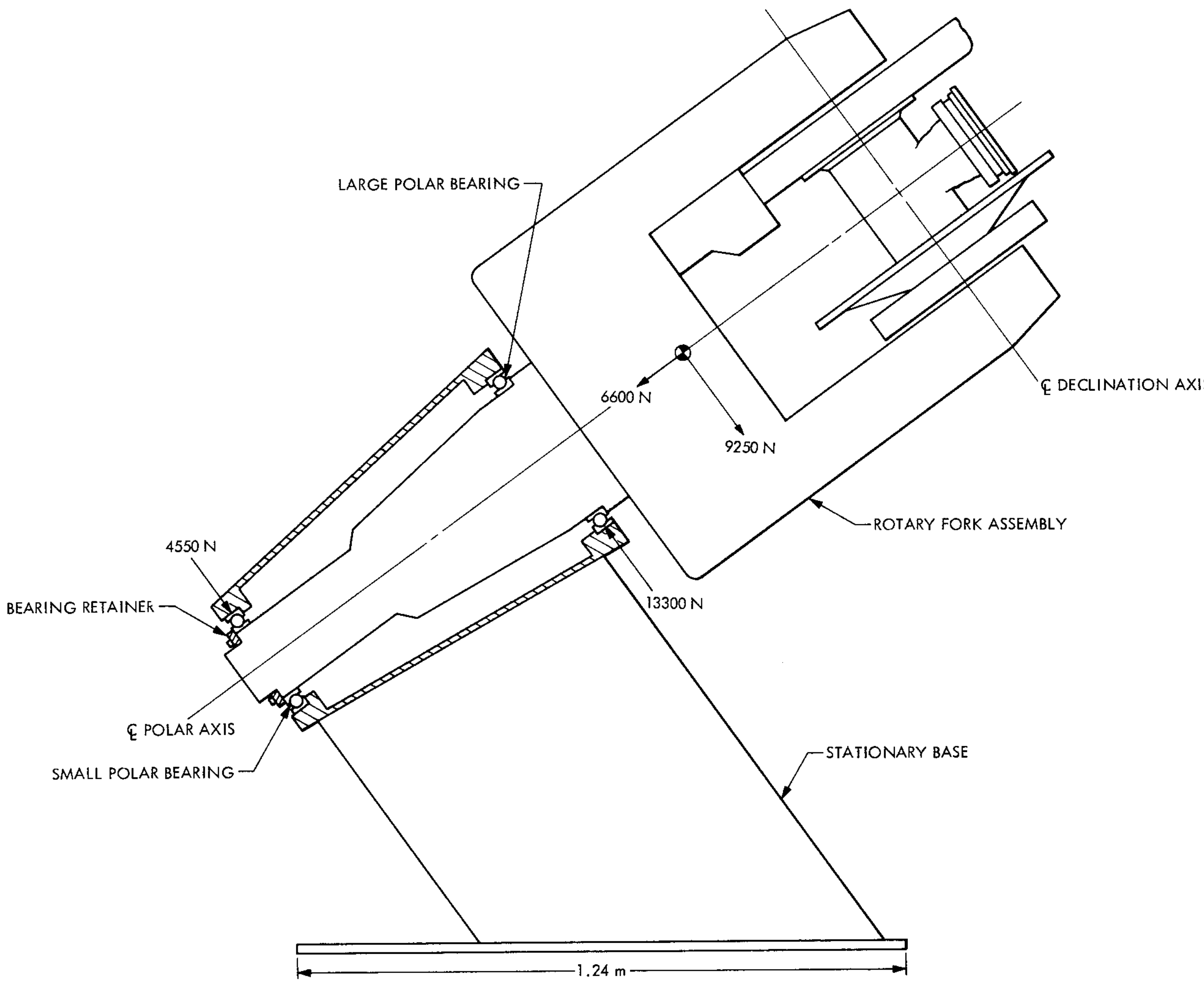

Fig. 1. Schematic of Master Equatorial showing polar axis bearings and loads (in Newtons)